IB Chemistry SL & HL Data Booklet

Table of Contents

1. Relevant Equations 2
2. Fundamental Constants 3
3. Metric Prefixes 3
4. Unit Conversions and Standard Conditions 3
5. Electromagnetic Spectrum 3
6. Names of the Elements 4
7. The Periodic Table 5
8. Melting Points and Boiling Points of the Elements at 101.325 kPa 5
9. First Ionization Energy, Electron Affinity, and Electronegativity of the Elements 6
10. Atomic and Ionic Radii of the Elements 6
11. Covalent Bond Lengths 7
12. Bond Enthalpies and Average Bond Enthalpies at 298.15 K 8
13. Thermodynamic Data (Selected Compounds) 9
14. Enthalpies of Combustion 10
15. Colour Wheel 11
16. Lattice Enthalpies (Experimental Values) at 298.15 K 12
17. Triangular Bonding Diagram (van Arkel–Ketelaar triangle) 13
18. Acid-base Indicators 14
19. Standard Reduction Potentials at 298.15 K 15
20. Infrared Data 16
21. ^{1}H NMR Data 16-17
22. Mass Spectral Fragments Lost 17
23. Uncertainties 18
24. References 18

1. Relevant Equations

Subtopic	Description	Equation
S1.4	Number of moles	$n = \frac{m}{M} = C \times V$ n= number of moles (mol), m= mass (g), M= molar mass (g mol^{-1}), C= concentration (mol dm^{-3}), V =volume (dm^3)
S1.5	Ideal Gas Equation	$PV = nRT$ P= pressure (Pa), V=volume (m^3), n= number of moles (mol), T= temperature (K)
S1.5	Combined Gas Law	$\frac{P1V1}{T1} = \frac{P2V2}{T2}$ P= pressure (Pa), V=volume (m^3), T= temperature (K)
S1.3H	Speed of light	$c = f\lambda$ c= speed of light (m s^{-1}), λ = wavelength (m), f = frequency (s^{-1})
S1.3H	Energy of photon of light	$E = hf$ E= energy (J), h = Plank's constant (J s), f = frequency (s^{-1})
R2.1	Atom economy	$\%\ atom\ economy = \frac{total\ mass\ of\ desired\ product}{total\ mass\ of\ all\ reactants} \times 100$
R1.1	Heat change	$Q = mc\Delta T$ Q= heat change (J), c= specific heat capacity (J $g^{-1}K^{-1}$), m = mass (g), ΔT= temperature change (K)
R1.2H	Standard enthalpy change of reaction	$\Delta H^\theta = \Sigma(\Delta H_f^\theta products) - \Sigma(\Delta H_f^\theta reactants) = \Sigma(\Delta H_c^\theta reactants) - \Sigma(\Delta H_c^\theta products)$ ΔH^θ= standard enthalpy change of reaction (kJ mol^{-1}), ΔH_f^θ= standard enthalpy change of formation (kJ mol^{-1}), ΔH_c^θ= standard enthalpy change of combustion (kJ mol^{-1})
R1.4	Gibbs free energy change	$\Delta G^\theta = \Delta H^\theta - T\Delta S^\theta$ ΔG^θ= standard Gibbs free energy change (kJ mol^{-1}), ΔH^θ = standard enthalpy change (kJ mol^{-1}), ΔS^θ = standard entropy change (J K^{-1} mol^{-1}), T = temperature (K)
R2.3H	Gibbs free energy change	$\Delta G^\theta = -RT\ lnK$ ΔG^θ= standard Gibbs free energy change (kJ mol^{-1}), R= gas constant (J $K^{-1}mol^{-1}$), T= temperature (K), K=equilibrium constant
R2.3H	Gibbs energy change	$\Delta G = \Delta G^\theta + RT\ lnQ$ ΔG^θ= standard Gibbs free energy change (kJ mol^{-1}), R= gas constant (J $K^{-1}mol^{-1}$), T= temperature (K), Q= reaction quotient
R3.2H	Gibbs free energy change	$\Delta G^\theta = -nFE^\theta$ ΔG^θ= standard Gibbs free energy change (J), n= number of moles of electrons transferred in the reaction (mol), F= Faraday's constant (C mol^{-1}), E^θ= standard cell potential (V)
R2.2H	Arrhenius equation	$k = A\,e^{-Ea/RT}$ k= rate constant, A = Arrhenius constant or frequency factor or pre-exponential factor, Ea= activation energy (Jmol^{-1}), R= gas constant (J $K^{-1}mol^{-1}$), T= temperature (K)
R2.2H	Linear form of Arrhenius equation	$lnk = \frac{-Ea}{RT} + lnA$ k= rate constant, A = Arrhenius constant or frequency factor or pre-exponential factor, Ea= activation energy (J mol^{-1}), R= gas constant (J $K^{-1}mol^{-1}$), T= temperature (K)
R3.1	Definition of pH	$pH = -log_{10}[H_3O^+]$ or $pH = -log_{10}[H^+]$
R3.1H	Definition of pOH	$pOH = -log_{10}[OH^-]$
R3.1	Ionic product constant	$K_w = [H^+][OH^-]$

2. Fundamental Constants

Symbol	Quantity	Approximate Value
N_A	Avogadro's constant	$6.02 \times 10^{23}\ mol^{-1}$
R	Gas constant	$8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$
V_m	Molar Volume of an ideal gas at STP	$22.7\ \text{dm}^3\ mol^{-1}$
c	Speed of light	$3.00 \times 10^8\ \text{m s}^{-1}$
c_w	Specific heat capacity of water	$4.18\ \text{J g}^{-1}\ K^{-1} = 4.18\ \text{kJ kg}^{-1}\ K^{-1}$
h	Planck's constant	$6.63 \times 10^{-34}\ J\ s$
F	Faraday's constant	$9.65 \times 10^4\ C\ \text{mol}^{-1}$
K_w	Ionic product constant for water (at 298.15 K)	$1.00 \times 10^{-14}\ \text{mol}^2\ \text{dm}^{-6}$
m_p	Proton rest mass	$1.672622 \times 10^{-27}\ \text{kg}$
m_n	Neutron rest mass	$1.674927 \times 10^{-27}\ \text{kg}$
m_e	Electron rest mass	$9.109384 \times 10^{-31}\ \text{kg}$
e	Elementary charge	$1.602177 \times 10^{-19}\ C$

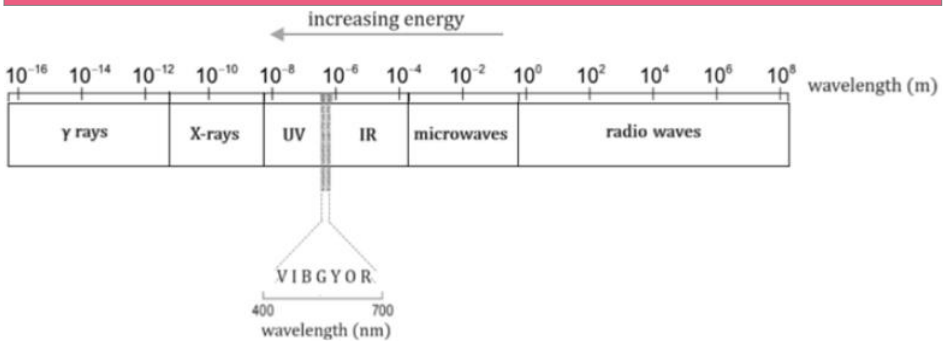
3. Metric Prefixes

Symbol	Prefix	Value
P	peta-	10^{15}
T	tera-	10^{12}
G	giga-	10^9
M	mega-	10^6
k	kilo-	10^3
h	hecto-	10^2
da	deca-	10^1
d	deci-	10^{-1}
c	centi-	10^{-2}
m	milli-	10^{-3}
μ	micro-	10^{-6}
n	nano-	10^{-9}
p	pico-	10^{-12}
f	femto-	10^{-15}

4. Unit Conversions and Standard Conditions

1 dm³	$1\ \text{L} = 1 \times 10^{-3}\ \text{m}^3 = 1 \times 10^3\ \text{cm}^3$
Temperature (K)	Temperature (°C) + 273.15
STP conditions	273.15 K and 100 kPa
SATP conditions	298.15 K and 100 kPa

5. Electromagnetic Spectrum



revisionvillage

6. Names of the Elements

Element	Symbol	Atomic Number
Actinium	Ac	89
Aluminium	Al	13
Americium	Am	95
Antimony	Sb	51
Argon	Ar	18
Arsenic	As	33
Astatine	At	85
Barium	Ba	56
Berkelium	Bk	97
Beryllium	Be	4
Bismuth	Bi	83
Bohrium	Bh	107
Boron	B	5
Bromine	Br	35
Cadmium	Cd	48
Caesium	Cs	55
Calcium	Ca	20
Californium	Cf	98
Carbon	C	6
Cerium	Ce	58
Chlorine	Cl	17
Chromium	Cr	24
Cobalt	Co	27
Copernicium	Cn	112
Copper	Cu	29
Curium	Cm	96
Darmstadtium	Ds	110
Dubnium	Db	105
Dysprosium	Dy	66
Einsteinium	Es	99
Erbium	Er	68
Europium	Eu	63
Fermium	Fm	100
Fluorine	F	9
Francium	Fr	87
Gadolinium	Gd	64
Gallium	Ga	31
Germanium	Ge	32
Gold	Au	79
Hafnium	Hf	72
Hassium	Hs	108
Helium	He	2
Holmium	Ho	67
Hydrogen	H	1
Indium	In	49

Element	Symbol	Atomic Number
Iodine	I	53
Iridium	Ir	77
Iron	Fe	26
Krypton	Kr	36
Lanthanum	La	57
Lawrencium	Lr	103
Lead	Pb	82
Lithium	Li	3
Lutetium	Lu	71
Magnesium	Mg	12
Manganese	Mn	25
Meitnerium	Mt	109
Mendelevium	Md	101
Mercury	Hg	80
Molybdenum	Mo	42
Neodymium	Nd	60
Neon	Ne	10
Neptunium	Np	93
Nickel	Ni	28
Niobium	Nb	41
Nitrogen	N	7
Nobelium	No	102
Osmium	Os	76
Oxygen	O	8
Palladium	Pd	46
Phosphorus	P	15
Platinum	Pt	78
Plutonium	Pu	94
Polonium	Po	84
Potassium	K	19
Praseodymium	Pr	59
Promethium	Pm	61
Protactinium	Pa	91
Radium	Ra	88
Radon	Rn	86
Rhenium	Re	75
Rhodium	Rh	45
Roentgenium	Rg	111
Rubidium	Rb	37
Ruthenium	Ru	44
Rutherfordium	Rf	104
Samarium	Sm	62
Scandium	Sc	21
Seaborgium	Sg	106
Selenium	Se	34

Element	Symbol	Atomic Number
Silicon	Si	14
Silver	Ag	47
Sodium	Na	11
Strontium	Sr	38
Sulfur	S	16
Tantalum	Ta	73
Technetium	Tc	43
Tellurium	Te	52
Terbium	Tb	65
Thallium	Tl	81
Thorium	Th	90
Thulium	Tm	69
Tin	Sn	50
Titanium	Ti	22
Tungsten	W	74
Uranium	U	92
Vanadium	V	23
Xenon	Xe	54
Ytterbium	Yb	70
Yttrium	Y	39
Zinc	Zn	30
Zirconium	Zr	40

7. The Periodic Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.01					Atomic number **Element** Relative atomic mass												2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.90
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 † **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.20	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 ‡ **Ac** (227)	104 **Rf** (267)	105 **Db** (268)	106 **Sg** (269)	107 **Bh** (270)	108 **Hs** (269)	109 **Mt** (278)	110 **Ds** (281)	111 **Rg** (281)	112 **Cn** (285)	113 **Uut** (286)	114 **Uuq** (289)	115 **Uup** (288)	116 **Uuh** (293)	117 **Uus** (294)	118 **Uuo** (294)

†	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
‡	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

8. Melting Points and Boiling Points of the Elements (at 101.325 kPa)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	-259.2 **H** -252.9					Melting point (℃) **Element** Boiling point (℃)												**He** -268.9
2	180.5 **Li** 1342	1287 **Be** 2468											2077 **B** 4000	3500 **C** 4827	-210.0 **N** -195.8	-218.8 **O** -183.0	-219.7 **F** -188.1	-248.6 **Ne** -246.0
3	97.79 **Na** 882.9	650.0 **Mg** 1090											660.3 **Al** 2519	1414 **Si** 3265	44.15 **P** 280.5	115.2 **S** 444.6	-101.5 **Cl** -34.04	-189.3 **Ar** -185.8
4	63.38 **K** 758.8	842.0 **Ca** 1484	1541 **Sc** 2836	1670 **Ti** 3287	1910 **V** 3407	1907 **Cr** 2671	1246 **Mn** 2061	1538 **Fe** 2861	1495 **Co** 2927	1455 **Ni** 2913	1085 **Cu** 2560	419.5 **Zn** 907.0	29.77 **Ga** 2229	938.2 **Ge** 2833	816.8 **As** 613.0	220.8 **Se** 684.8	-7.050 **Br** 58.78	-157.4 **Kr** -153.4
5	39.30 **Rb** 687.8	768.8 **Sr** 1377	1522 **Y** 3345	1854 **Zr** 4406	2477 **Nb** 4741	2622 **Mo** 4639	2157 **Tc** 4262	2333 **Ru** 4147	1963 **Rh** 3695	1555 **Pd** 2963	961.8 **Ag** 2162	321.1 **Cd** 766.8	156.6 **In** 2027	231.9 **Sn** 2586	630.6 **Sb** 1587	449.5 **Te** 987.8	113.7 **I** 184.4	-111.8 **Xe** -108.1
6	28.44 **Cs** 670.8	725.0 **Ba** 1845	920.0 † **La** 3464	2233 **Hf** 4600	3017 **Ta** 5455	3414 **W** 5555	3453 **Re** 5900	3033 **Os** 5008	2446 **Ir** 4428	1768 **Pt** 3825	1064 **Au** 2836	-38.83 **Hg** 356.6	303.8 **Tl** 1473	327.5 **Pb** 1749	271.4 **Bi** 1564	253.8 **Po** 962.0	301.8 **At** 336.8	-71.15 **Rn** -61.85
7	27.00 **Fr** 676.8	699.8 **Ra** 1140	1050 **Ac** ‡ 3200															

†	795 **Ce** 3433	935 **Pr** 3510	1024 **Nd** 3074	1042 **Pm** (2730)	1072 **Sm** 1791	826 **Eu** 1596	1313 **Gd** 3273	1360 **Tb** 3230	1410 **Dy** 2567	1472 **Ho** 2694	1529 **Er** 2900	1545 **Tm** 1950	824 **Yb** 1194	1663 **Lu** 3042
‡	1750 **Th** 4788	1572 **Pa** (4000)	1135 **U** 3818	637 **Np** (3900)	640 **Pu** 3230	1176 **Am** (2067)	1340 **Cm** 3110	986 **Bk** (2623)	900 **Cf**	(860) **Es**	**Fm**	827 **Md**	**No**	**Lr**

9. First Ionization Energy, Electron Affinity, and Electronegativity of the Elements

First ionization energy (kJ mol^{-1}) | Electron affinity (kJ mol^{-1}) | 2nd EA (kJ mol^{-1})

Element

Electronegativity

1312 -73 **H** 2.2																2372 **He**
520 -60 **Li** 1.0	900 **Be** 1.6											801 -27 **B** 2.0	1086 -122 **C** 2.6	1402 **N** 3.0	1314 -141 (+753) **O** 3.4	1681 -328 **F** 4.0	2081 **Ne**
496 -53 **Na** 0.9	738 **Mg** 1.3											578 -42 **Al** 1.6	787 -134 **Si** 1.9	1012 -72 **P** 2.2	1000 -200 (+545) **S** 2.6	1251 -349 **Cl** 3.2	1520 **Ar**
419 -48 **K** 0.8	590 -2 **Ca** 1.0	633 -18 **Sc** 1.4	659 -8 **Ti** 1.5	651 -51 **V** 1.6	653 -64 **Cr** 1.7	717 **Mn** 1.6	762 -15 **Fe** 1.8	760 -64 **Co** 1.9	737 -112 **Ni** 1.9	745 -119 **Cu** 1.9	906 **Zn** 1.6	579 -41 **Ga** 1.8	762 -119 **Ge** 2.0	944 -78 **As** 2.2	941 -195 **Se** 2.6	1140 -325 **Br** 3.0	1351 **Kr**
403 -47 **Rb** 0.8	549 -5 **Sr** 1.0	600 -30 **Y** 1.2	640 -41 **Zr** 1.3	652 -88 **Nb** 1.6	684 -72 **Mo** 2.2	702 -53 **Tc** 2.1	710 -101 **Ru** 2.2	720 -110 **Rh** 2.3	804 -54 **Pd** 2.2	731 -126 **Ag** 1.9	868 **Cd** 1.7	558 -29 **In** 1.8	709 -107 **Sn** 2.0	831 -101 **Sb** 2.0	869 -190 **Te** 2.1	1008 -295 **I** 2.7	1170 **Xe** 2.6
376 -46 **Cs** 0.8	503 -14 **Ba** 0.9	538 -45 **La** † 1.1	659 -1 **Hf** 1.3	728 -31 **Ta** 1.5	759 -79 **W** 1.7	756 -14 **Re** 1.9	814 -106 **Os** 2.2	865 -151 **Ir** 2.2	864 -205 **Pt** 2.2	890 -223 **Au** 2.4	1007 **Hg** 1.9	589 -36 **Tl** 1.8	716 -35 **Pb** 1.8	703 -91 **Bi** 1.9	812 -183 **Po** 2.0	-270 **At** 2.2	1037 **Rn**
393 -47 **Fr** 0.7	509 -10 **Ra** 0.9	499 -34 **Ac** ‡ 1.1															

†	534 -64 **Ce** 1.1	528 -93 **Pr** 1.1	533 -185 **Nd** 1.1	539 **Pm**	545 **Sm** 1.2	547 -83 **Eu**	593 **Gd** 1.2	566 -112 **Tb**	573 <0 **Dy** 1.2	581 **Ho** 1.2	589 **Er** 1.2	597 -99 **Tm** 1.3	603 2 **Yb**	524 -33 **Lu** 1.0
‡	609 **Th** 1.3	568 **Pa** 1.5	598 **U** 1.7	605 **Np** 1.3	581 **Pu** 1.3	576 **Am**	578 **Cm**	598 **Bk**	606 **Cf**	619 **Es**	627 **Fm**	635 **Md**	642 **No**	473 **Lr**

10. Atomic and Ionic Radii of the Elements

Atomic radius (10^{-12} m)

Element

Ionic radius (10^{-12} m)

32 **H**																37 **He**
130 **Li** 76 (1+)	99 **Be** 45 (2+)											84 **B** 27 (3+)	75 **C** 16 (4+)	71 **N** 146 (3-)	64 **O** 140 (2-)	60 **F** 133 (1-)	62 **Ne**
160 **Na** 102 (1+)	140 **Mg** 72 (2+)											124 **Al** 54 (3+)	114 **Si** 40 (4+)	109 **P** 38 (5+)	104 **S** 184 (2-)	100 **Cl** 181 (1-)	101 **Ar**
200 **K** 138 (1+)	174 **Ca** 100 (2+)	159 **Sc** 75 (3+)	148 **Ti** 86 (2+) 61 (4+)	144 **V** 79 (2+) 54 (5+)	130 **Cr** 62 (3+) 44 (6+)	129 **Mn** 83 (2+) 53 (4+)	124 **Fe** 61 (2+) 55 (3+)	118 **Co** 65 (2+) 55 (3+)	117 **Ni** 69 (2+)	122 **Cu** 77 (1+) 73 (2+)	120 **Zn** 74 (2+)	123 **Ga** 62 (3+)	120 **Ge** 53 (4+) 272 (4-)	120 **As** 58 (3+) 46 (5+)	118 **Se** 198 (2-)	117 **Br** 196 (1-)	116 **Kr**
215 **Rb** 152 (1+)	190 **Sr** 118 (2+)	176 **Y** 90 (3+)	164 **Zr** 72 (4+)	156 **Nb** 72 (3+) 64 (5+)	146 **Mo** 65 (4+)	138 **Tc** 65 (4+)	136 **Ru** 68 (3+) 62 (4+)	134 **Rh** 67 (3+) 60 (4+)	130 **Pd** 86 (2+) 62 (4+)	136 **Ag** 115 (1+)	140 **Cd** 95 (2+)	142 **In** 80 (3+)	140 **Sn** 118 (2+) 69 (4+)	140 **Sb** 76 (3+)	137 **Te** 221 (2-)	136 **I** 220 (1-)	136 **Xe**
238 **Cs** 167 (1+)	206 **Ba** 135 (2+)	194 **La** † 103 (3+)	164 **Hf** 71 (4+)	158 **Ta** 64 (5+)	150 **W** 66 (4+) 60 (6+)	141 **Re** 63 (4+) 53 (7+)	136 **Os** 63 (4+) 55 (6+)	132 **Ir** 68 (3+) 63 (4+)	130 **Pt** 80 (2+) 63 (4+)	130 **Au** 137 (1+) 85 (3+)	132 **Hg** 119 (1+) 102 (2+)	144 **Tl** 150 (1+) 89 (3+)	145 **Pb** 119 (2+) 78 (4+)	150 **Bi** 103 (3+) 76 (5+)	142 **Po** 97 (4+)	148 **At**	146 **Rn**
242 **Fr**	211 **Ra**	201 **Ac** ‡															

†	184 **Ce** 101 (3+) 87 (4+)	190 **Pr** 99 (3+) 85 (4+)	188 **Nd** 98 (3+)	186 **Pm** 97 (3+)	185 **Sm** 96 (3+)	183 **Eu** 117 (2+) 95 (3+)	182 **Gd** 94 (3+)	65 **Tb** 92 (3+) 76 (4+)	66 **Dy** 91 (3+)	67 **Ho** 90 (3+)	68 **Er** 89 (3+)	69 **Tm** 88 (3+)	70 **Yb** 87 (3+)	71 **Lu** 86 (3+)
‡	190 **Th** 94 (4+)	184 **Pa** 104 (3+) 90 (4+)	183 **U** 89 (4+) 73 (6+)	180 **Np** 101 (3+) 87 (4+)	180 **Pu** 100 (3+) 86 (4+)	173 **Am** 98 (3+) 85 (4+)	168 **Cm** 97 (3+)	97 **Bk** 96 (3+)	98 **Cf** 99 (3+)	99 **Es**	100 **Fm**	101 **Md**	102 **No** 110 (2+)	103 **Lr**

11. Covalent Bond Lengths

Single bonds (10^{-12} m = pm)

	Br	C	Cl	F	H	I	N	O	P	S	Si
Br	228	194	214	176	141	247	214		220	227	216
C	194	154	177	138	108	214	147	143	184	182	185
Cl	214	177	199	163	128	232	197	170	203	199	202
F	176	138	163	142	92	257	136	142	154	158	156
H	141	108	128	92	74	160	101	97	142	134	148
I	247	214	232	257	160	267			247		243
N	214	147	197	136	101		146	136		175	174
O		143	170	142	97		136	148	154	161	163
P	220	184	203	154	142	247		154	221	210	
S	227	182	199	158	134		175	161	210	205	215
Si	216	185	202	156	148	243	174	163		215	232

Multiple bonds (10^{-12} m = pm)

Bond	Length (10^{-12}m)	Bond	Length (10^{-12}m)	Bond	Length (10^{-12}m)
C = N	130	N = N	125	O = O	121
C = O	122	N = O	114	O = S	143
C = S	156				
C = C	134			S = S	189
C ≡ O	113	N ≡ N	110		
C ≡ N	116				
C ≡ C	120				

12. Bond Enthalpies and Average Bond Enthalpies at 298.15 K

Single bonds (kJ mol^{-1})

	Br	C	Cl	F	H	I	N	O	P	S	Si
Br	193	285	219	249	366	178		201	264	218	330
C	285	346	324	492	414	228	286	358	264	289	307
Cl	219	324	242	255	431	211	192	206	322	271	400
F	249	492	255	159	567	280	278	191	490	327	597
H	366	414	431	567	436	298	391	463	322	364	323
I	178	228	211	280	298	151		201	184		234
N		286	192	278	391		158	214			
O	201	358	206	191	463	201	214	144	363		466
P	264	264	322	490	322	184		363	198		
S	218	289	271	327	364					266	293
Si	330	307	400	597	323	234		466		293	226

Multiple bonds (kJ mol^{-1})

Bond	Enthalpy (kJ mol^{-1})	Bond	Enthalpy (kJ mol^{-1})	Bond	Enthalpy (kJ mol^{-1})
C = N	615	N = N	470	O = O	498
C = O	804	N = O	587	O = S	522
C = S	536				
C = C	614			S = S	429
C ≡ O	1077	N ≡ N	945		
C ≡ N	890				
C ≡ C	839				

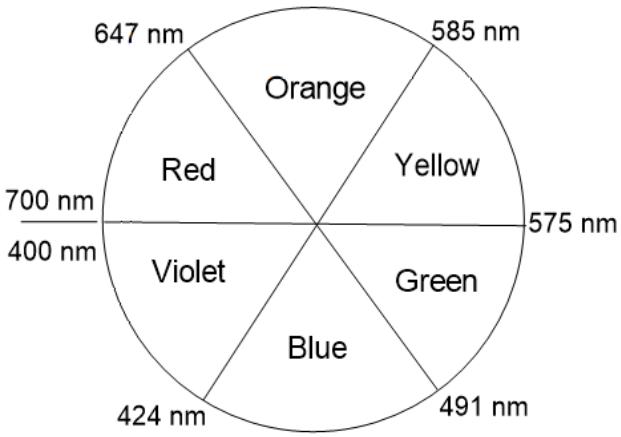
13. Thermodynamic Data (Selected Compounds)					
Substance	**Formula**	**State**	**$\Delta H_f^{\ominus}$ (kJ mol^{-1})**	**$\Delta G_f^{\ominus}$ (kJ mol^{-1})**	**$S^{\ominus}$(J K^{-1}mol^{-1})**
Methane	CH_4	g	-74	-50	+186
Ethane	C_2H_6	g	-84	-32	+230
Propane	C_3H_8	g	-105	-24	+270
Butane	C_4H_{10}	g	-126	-17	+310
Pentane	C_5H_{12}	l	-173		
Hexane	C_6H_{14}	l	-199		
Ethene	C_2H_4	g	+52	+68	+220
Propene	C_3H_6	g	+20	+62	+267
But-1-ene	C_4H_8	g	+0.1	+71	+306
Cis-but-2-ene	C_4H_8	g	-7	+66	+301
Trans-but-2-ene	C_4H_8	g	-11	+63	+297
Ethyne	C_2H_2	g	+228	+211	+201
Propyne	C_3H_4	g	+185	+194	+248
Buta-1,3-diene	C_4H_6	g	+110	+151	+279
Cyclohexane	C_6H_{12}	l	-156		
Benzene	C_6H_6	l	+49	+125	+173
Methylbenzene	$C_6H_5CH_3$	l	+12		
Ethylbenzene	$C_6H_5CH_2CH_3$	l	-12		
Phenylethene	$C_6H_5CHCH_2$	l	+104		
Chloromethane	CH_3Cl	g	-82	-58.0	+235
Dichloromethane	CH_2Cl_2	l	-124		+178
Trichloromethane	$CHCl_3$	l	-134	-74	+202
Bromomethane	CH_3Br	g	-36	-26	+246
Iodomethane	CH_3I	l	-14		+163
Chloroethane	C_2H_5Cl	g	-137	-53	
Bromoethane	C_2H_5Br	l	-90	-26	+199
Chlorobenzene	C_6H_5Cl	l	+11		
Methanol	CH_3OH	l	-239	-167	+127
Ethanol	C_2H_5OH	l	-278	-175	+161
Phenol	C_6H_5OH	s	-165		+144
Methanal	HCHO	g	-109	-102	+219
Ethanal	CH_3CHO	g	-166	-133	+264
Propanone	$(CH_3)_2CO$	l	-248		+200
Methanoic acid	HCOOH	l	-425	-361	+129
Ethanoic acid	CH_3COOH	l	-484	-390	+160
Benzoic acid	C_6H_5COOH	s	-385		+168
Methylamine	CH_3NH_2	g	-23	+32	+243
Water	H_2O	l	-286	-237	+70
Steam	H_2O	g	-242	-229	+189
Carbon monoxide	CO	g	-111	-137	+198
Carbon dioxide	CO_2	g	-394	-394	+214
Hydrogen bromide	HBr	g	-36	-53	+199
Hydrogen chloride	HCl	g	-92	-95	+187
Hydrogen fluoride	HF	g	-27	-275	+174
Hydrogen iodide	HI	g	+26	+2	+207

14. Enthalpies of Combustion

(The molar enthalpy of combustion ($\Delta H_c^{\ominus}$) values shown in the table below were collected at SATP conditions)

Substance	Formula	State	$\Delta H_c^{\ominus}$ (kJ mol^{-1})
Hydrogen	H_2	g	-286
Sulfur	S	s	-297
Carbon (graphite)	C	s	-394
Carbon monoxide	CO	g	-283
Methane	CH_4	g	-891
Ethane	C_2H_6	g	-1561
Propane	C_3H_8	g	-2219
Butane	C_4H_{10}	g	-2878
Pentane	C_5H_{12}	l	-3509
Hexane	C_6H_{14}	l	-4163
Octane	C_8H_{18}	l	-5470
Cyclohexane	C_6H_{12}	l	-3920
Ethene	C_2H_4	g	-1411
Buta-1,3-diene	C_4H_6	g	-2541
Ethyne	C_2H_2	g	-1301
Benzene	C_6H_6	l	-3268
Methylbenzene	$C_6H_5CH_3$	l	-3910
Naphthalene	$C_{10}H_8$	s	-5156
Chloroethane	C_2H_5Cl	g	-1413
Iodoethane	C_2H_5I	l	-1463
Trichloromethane	$CHCl_3$	l	-473
Methanol	CH_3OH	l	-726
Ethanol	C_2H_5OH	l	-1367
Propan-1-ol	C_3H_7OH	l	-2021
Butan-1-ol	C_4H_9OH	l	-2676
Cyclohexanol	$C_6H_{11}OH$	s	-3728
Phenol	C_6H_5OH	s	-3053
Ethoxyethane	$(C_2H_5)_2O$	l	-2724
Methanal	HCHO	g	-571
Ethanal	CH_3CHO	g	-1167
Benzaldehyde	C_6H_5CHO	l	-3525
Propanone	$(CH_3)_2CO$	l	-1790
Pentan-3-one	$(C_2H_5)_2CO$	l	-3100
Phenylethanone	$CH_3COC_6H_5$	l	-4149
Methanoic acid	HCOOH	l	-255
Ethanoic acid	CH_3COOH	l	-874
Benzoic acid	C_6H_5COOH	s	-3228
Ethanedioic acid	$(COOH)_2$	s	-243
Ethyl ethanoate	$CH_3COOC_2H_5$	l	-2238
Ethanamide	CH_3CONH_2	s	-1186
Methylamine	CH_3NH_2	g	-1086
Phenylamine	$C_6H_5NH_2$	l	-3393
Nitrobenzene	$C_6H_5NO_2$	l	-3088
Urea	$CO(NH_2)_2$	s	-633
Glucose	$C_6H_{12}O_6$	s	-2803
Sucrose	$C_{12}H_{22}O_{11}$	s	-5640

15. Colour Wheel



16. Lattice Enthalpies at 298.15 K (experimental values)

The provided lattice enthalpy values ($\Delta H^{\ominus}_{lattice}$) correspond to the endothermic process M_aX_b (s) → aM^{b+} (g) + bX^{a-} (g), which involves the separation of gaseous ions of a crystal to an infinite distance from each other.

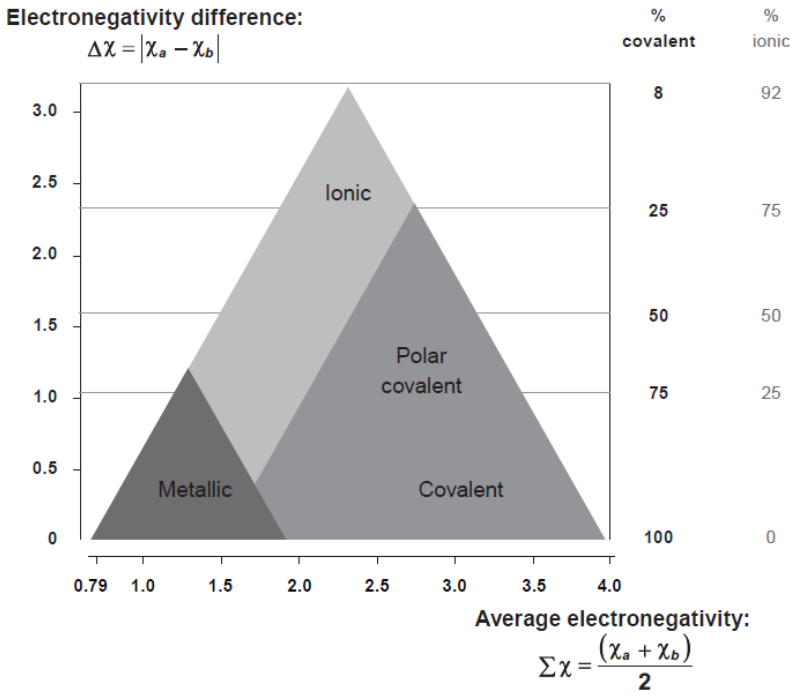
Experimental Values *(Adequate Born-Haber cycle was used to obtain the values in the tables below)*

Alkali metal halides	$\Delta H^{\ominus}_{lattice}$(kJ mol^{-1})			
	F	**Cl**	**Br**	**I**
Li	1049	864	820	764
Na	930	790	754	705
K	829	720	691	650
Rb	795	695	668	632
Cs	759	670	647	613

Other substances	$\Delta H^{\ominus}_{lattice}$(kJ mol^{-1})
CaF_2	2651
$BeCl_2$	3033
$MgCl_2$	2540
$CaCl_2$	2271
$SrCl_2$	2170
$BaCl_2$	2069
MgO	3791
CaO	3401

Other substances	$\Delta H^{\ominus}_{lattice}$(kJ mol^{-1})
SrO	3223
BaO	3054
$CuCl_2$	2824
AgF	974
AgCl	918
AgBr	905
AgI	892

17. Triangular Bonding Diagram (van Arkel–Ketelaar triangle)



18. Acid-base Indicators

			Colour change	
Indicator	**pK_a**	**pH range**	**Acid**	**Alkali**
Methyl orange	3.7	3.1-4.4	Red	Yellow
Bromophenol blue	4.2	3.0-4.6	Yellow	Blue
Bromocresol green	4.7	3.8-5.4	Yellow	Blue
Methyl red	5.1	4.4-6.2	Red	Yellow
Bromothymol blue	7.0	6.0-7.6	Yellow	Blue
Phenol red	7.9	6.8-8.4	Yellow	Red
Phenolphthalein	9.6	8.3-10.0	Colourless	Pink

19. Standard Reduction Potentials at 298.15 K

Oxidized species ⇌ Reduced species	$E^{\ominus}$(V)
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	-3.04
$K^+(aq) + e^- \rightleftharpoons K(s)$	-2.93
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	-2.87
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	-2.71
$Mg^{2+} + 2e^- \rightleftharpoons Mg(s)$	-2.37
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	-1.66
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	-1.18
$H_2O(l) + e^- \rightleftharpoons ½\ H_2(g) + OH^-(aq)$	-0.83
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	-0.76
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	-0.45
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	-0.26
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	-0.14
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	-0.13
$H^+(aq) + e^- \rightleftharpoons ½\ H_2(g)$	0.00
$Cu^{2+}(aq) + e^- \rightleftharpoons Cu^+(aq)$	+0.15
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons H_2SO_3(aq) + H_2O(l)$	+0.17
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$½\ O_2(g) + H_2O(l) + 2e^- \rightleftharpoons 2OH^-(aq)$	+0.40
$Cu^+(aq) + e^- \rightleftharpoons Cu(s)$	+0.52
$½\ I_2(s) + e^- \rightleftharpoons I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$½\ Br_2(l) + e^- \rightleftharpoons Br^-(aq)$	+1.09
$½\ O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O(l)$	+1.23
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.36
$½\ Cl_2(g) + e^- \rightleftharpoons Cl^-(aq)$	+1.36
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O(l)$	+1.51
$½\ F_2(g) + e^- \rightleftharpoons F^-(aq)$	+2.87

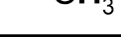
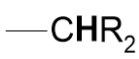
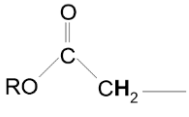
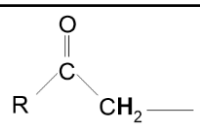
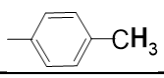
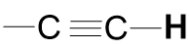
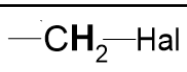
20. Infrared Data

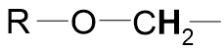
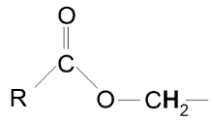
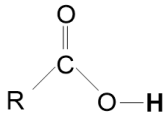
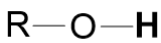
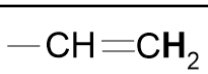
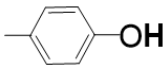
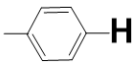
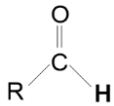
Distinctive intervals for infrared absorption arising from stretching vibrations in organic compounds.

Bond	Organic molecules	Wavenumber (cm^{-1})	Intensity
C – I	Iodoalkanes	490 – 620	Strong
C – Br	Bromoalkanes	500 – 600	Strong
C – Cl	Chloroalkanes	600 – 800	Strong
C – F	Fluoroalkanes	1000 – 1400	Strong
C – O	Alcohols, esters, ethers	1050 – 1410	Strong
C = C	Alkenes	1620 – 1680	Medium-weak; multiple bands
C = O	Aldehydes, ketones, carboxylic acids, esters	1700 – 1750	Strong
C ≡ C	Alkynes	2100 – 2260	Variable
O – H	Carboxylic acids (with hydrogen bonding)	2500 – 3000	Strong, very broad
C – H	Alkanes, alkenes, arenes	2850 – 3090	Strong
O – H	Alcohols and phenols (with hydrogen bonding)	3200 – 3600	Strong, broad
N – H	Primary amines	3300 – 3500	Medium, two bands

21. ^{1}H NMR Data

Common proton chemical shift values (δ) are referenced to tetramethylsilane (TMS) = 0.
An alkyl group is represented by R, and the elements F, Cl, Br, or I are represented by Hal.
Different solvents and conditions may cause variations in these values.

Type of proton	Chemical shift (ppm)
	0.9 – 1.0
	1.3 – 1.4
	1.5
	2.0 – 2.5
	2.2 – 2.7
	2.5 – 3.5
	1.8 – 3.1
	3.5 – 4.4

Type of proton	Chemical shift (ppm)
	3.3 – 3.7
	3.7 – 4.8
	9.0 – 13.0
	1.0 – 6.0
	4.5 – 6.0
	4.0 – 12.0
	6.9 – 9.0
	9.4 – 10.0

22. Mass Spectral Fragments Lost

Mass Lost	Neutral Fragment, Possibly Lost
15	•CH_3
17	•OH
18	H_2O
28	$CH_2 = CH_2$ C = O
29	•CH_2CH_3 •CHO
31	•OCH_3
45	•COOH

If: $y = a \pm b$	Then: $\Delta y = \Delta a + \Delta b$
If: $y = \frac{ab}{c}$	Then: $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$
If: $y = a^n$	Then: $\frac{\Delta y}{y} = \left\| n \frac{\Delta a}{a} \right\|$

24. References

Data in sections 7, 8, 9, 10, 11, 12, 13, 14, 16, 18, 19, 20, 21 and 22 were taken fully or in part from:
Blackman, A., Gahan, L. R., Aylward, G. H., & Findlay, T. J. V. (2014). *Aylward and Findlay's SI Chemical Data*. (7th ed.). John Wiley & Sons.
National Institute of Standards and Technology. (2021). *NIST Chemistry WebBook SRD 69, NIST Standard Reference Database*. U.S. Department of Commerce. http://webbook.nist.gov
Rumble, J. R. (Ed.). (2019). *CRC Handbook of Chemistry and Physics*. (100th ed.). CRC Press.

Data in section 17 are reproduced with permission from the author:
Leach, M. R. (2021). *The Chemogenesis Web Book: Timeline of structural theory*. http://www.meta-synthesis.com/webbook/30_timeline/timeline.html